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Harmonization of hydropower plant with the environment

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Abstract

The influence of a hydropower plant on the environment is analyzed. The frequent starting and stopping of hydropower plant turbines are considered to cause the erosion of river-bed and damage to river flora, fauna and the environment generally. The harm may be reduced by passing the entire runoff of the river through turbines without changing the flow of runoff and the accumulation of water in a reservoir [Klimpt J-E, Riveiro C, Puranen H, Koch F. Recommendations for sustainable hydroelectric development. Energy Policy 2002; 30(14): 1305–1312]. This idea cannot be realized in a traditional hydropower plant. The range of runoff changes of Lithuanian rivers is much broader than the capacity of one or more turbines of the same power.

The characteristics of several turbine types are analyzed. The carrying capacity of a cross flow turbine is regarded to have the widest range. In addition, the width of the range may be expanded with special auxiliary equipment. This type of turbine is equivalent to two or even three turbines of varying capacities, and it can handle the discharges from any season.

The possibilities for expanding the range of turbine capacity by means of working with varying speeds of rotation are discussed. Special mechatronic systems for controlling mechanical and electrical equipment of a hydropower plant, working with varying speed of turbines revolution, are presented. The investigation of mathematical models of the systems under both autonomous and systematic regimes shows their efficient operation and sufficient quality of electrical power.

Keywords: River runoff; Turbine; Capacity; Efficiency; Mechatronic system

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Contents

1. Introduction

As environmental protection requirements with regard to energy production technologies become evermore strict, inevitably therefore cleaner renewable energy sources attract more attention. Based on the experience of many centuries, hydropower is one of the most popular of these sources. The energy of the river water flow is easily concentrated, but its development induces the flooding of significant areas, changes the landscape, the river hydraulic regime and the living conditions of water fauna and flora in the long reach of the river. Some of these changes are harmful, and others are useful. The reduction of harmful factors caused by hydropower development is the aim of our work [1].

After the construction of a valley-type hydropower plant (HPP) and filling of the reservoir, water depth increases upstream of the plant, and its velocity decreases. Fish communities [2,3] as well as the sorts of plants change. Due to the elevation of the open and ground water level, the microclimate [4], flora and fauna alter within the area surrounding the reservoir. The flow regime downstream becomes different from that of the natural river flow and is influenced by the HPP work regime. Each change of turbine work regime causes sudden fluctuations of water level. Due to these phenomena long-lasting scour goes on in a river bed [5]. The living conditions are intolerable for fish communities, and for this reason their populations are reduced or they vanish completely [6]. The determination of the influence of a HPP on the river flow regime in the downstream reach and the measures, which can be taken to reduce its strength are the aim of our work.

2. Alternation of Lithuanian river runoff

The alternation of the flow parameters velocity, depth and discharge along the river over time is here called the flow regime. In order to define the influence of a HPP on the river flow regime, we have analyzed it in comparison with the regime under natural conditions. Lithuanian river runoff varies in time within a great range whose width depends on many factors. It is commonly known that river regime parameters reach maximum magnitudes in Spring flood time and minimum in Summer drought and also in Winter cold periods (see Fig. 1). The amplitudes of parameter alternation depend first of all on the presence of lakes, reservoirs, forests, and swamps in the river basin, accumulating and restraining the water precipitation.

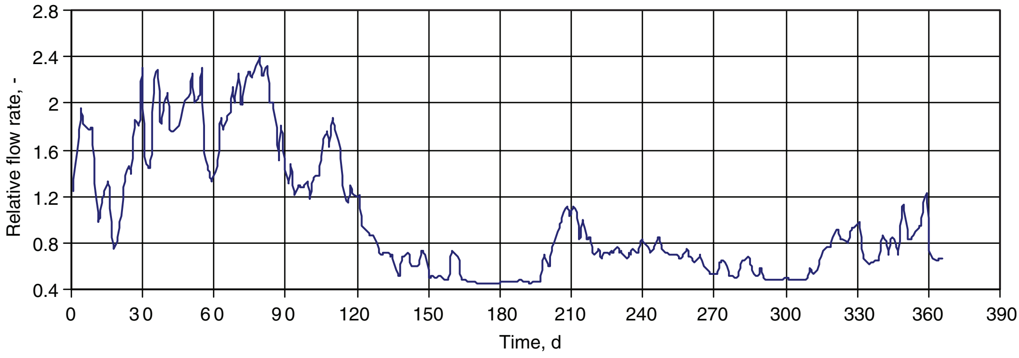


Fig. 1. Discharge hydrograph of the Nemunas in 2000.

The type of river feeding plays an important role in runoff fluctuation over time. Small amplitude of discharge alternation is common for ground-feeding rivers. A sudden fluctuation with great amplitude is typical for the surface and mixed feeding rivers (Fig. 1). Spring flood is evident in a hydrograph of a surface-feeding river, while increment in discharge due to snow melting is invisible in a hydrograph of a ground-water-feeding river.

The speed of river flow depth and velocity change is very important for river bed processes, therefore, we have thoroughly investigated this peculiarity of the flow regime. Rainfall over a long period but of a small intensity causes a slow rise in the water level and a gradual lowering when it stops. A short and intensive downpour bringing the same amount of precipitation causes a much more sudden fluctuation of the water level. 10 to 20 distinct peaks may be seen on any annual hydrograph of Lithuanian rivers (see Fig. 1).

We have analyzed the observation data [7] of the Nemunas flow level at Smalininkai Station. Within the period 1812–1929, we have found the maximum speed of water level rise is 151 cm/day (5–6/08/1925) and the drop speed to be 49 cm/day (29–30/07/1881). Only the Summer (June–October) period data has been examined; therefore, only heavy showers can be the reason for the indicated peaks of sudden rises and drops in the level. Water level fluctuations speed $\leqslant$10 cm/day is much more frequent and happens every year.

Ice phenomena also create fluctuations in water level. At the time of ice cover formation and breaking, the water level usually fluctuates at a speed of 15–30 cm/day [7]. Sometimes the water level undergoes even greater changes due to ice phenomena. On 23/12/1849 during ice cover formation on the Nemunas at Smalininkai, the water level rose at a speed of 97 cm/day. Ice blocks cause more sudden fluctuations in the water level. During the debacle of 12/03/1827, the water level at Smalininkai rose by 252 cm. Next day on 13th March it dropped down to 272 cm [7]. Thus, the drop speed was $\geqslant$272 cm/day = 11.33 cm/h.

The formation of an ice block leads to a sudden rise in the water level in the river both upstream and drop downstream the block. This fact may not be determined in old records of the water level as it had been measured only once or twice a day with a 12 h interval. Thus, the level drop indicated above allows us to state that the level-lowering speed was not lower than 272 cm/day. After the ice block break, water flows with a much greater

discharge and higher velocity than during the largest normal flood. The self-lining layer of a river bed [4] is damaged at the time of ice block formation and collapse. It may also happen during an extremely large normal flood without any ice. When the lining layer is damaged, long lasting bed scour starts. Fortunately, ice phenomena and extreme floods are rather rare; therefore their effect on the processes transforming a river bed is not great.

The impact of human activities as described in our previous work [8] has many forms. Some of them are of a permanent character, and their influence is quite significant. We have investigated only the impact of hydropower development on the river flow downstream of the HPP. Our preliminary idea of harmonized hydropower development is based on the assumption that minimum change of natural river flow is optimal to the environment. Keeping the water level in a reservoir at a nominal rate, avoiding the bypass of water through a spillway may be considered as the optimum approach and harmonious.

River runoff varies in time within definite limits. They are the most important parameters of river hydropower quality. A broad range of discharge variation means difficulties in hydropower utilization. The limits are seen from a hydrograph, notwithstanding the fact that chaotic variation in a discharge magnitude is not convenient for engineering computations. For this purpose we suggest the use of a graph of relative discharge Q/Q_o, aligned to statistical series, named below a statistical hydrograph (see Figs. 2 and 3). We consider it to be the most universal and convenient tool for the analysis of river runoff and for the estimation of river hydropower potential quality.

The character of river runoff distribution over time becomes evident when comparing statistical hydrographs of different rivers from the same year (see Fig. 2)—the differences are evident. The hydrographs of a different year for the same river are very similar, despite the difference in climatic conditions, thus confirming the correctness of the idea. Three years: the driest (1812), median (1885) and the wettest (1928) were selected from a long period (1812–1929) of the Nemunas observation at Smalininkai for comparing statistical hydrographs (see Fig. 3). Despite the great difference in average annual discharges (285, 580 and 874 m^3/s, respectively), and the distribution of discharge in time, the statistical hydrographs are quite similar. It is clear that a statistical hydrograph is an excellent tool for determining of hydropower potential, discharge variation limits, and the selection of turbines for a HPP.

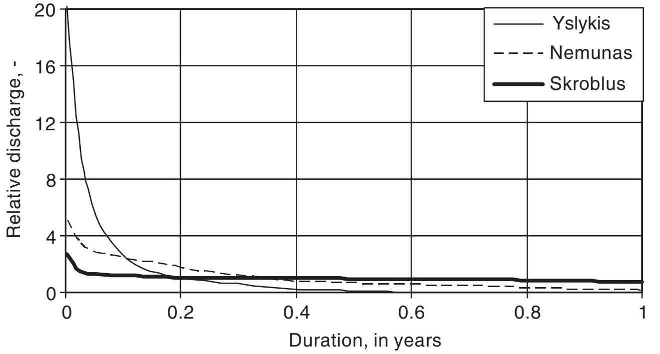


Fig. 2. Statistical hydrographs of theYslykis, the Nemunas (Smalininkai) and the Skroblus for 2000.

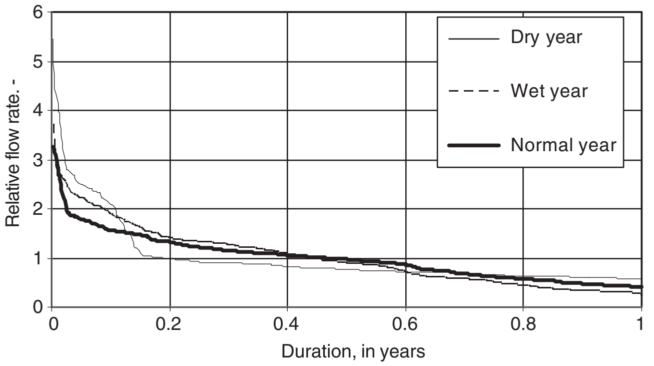
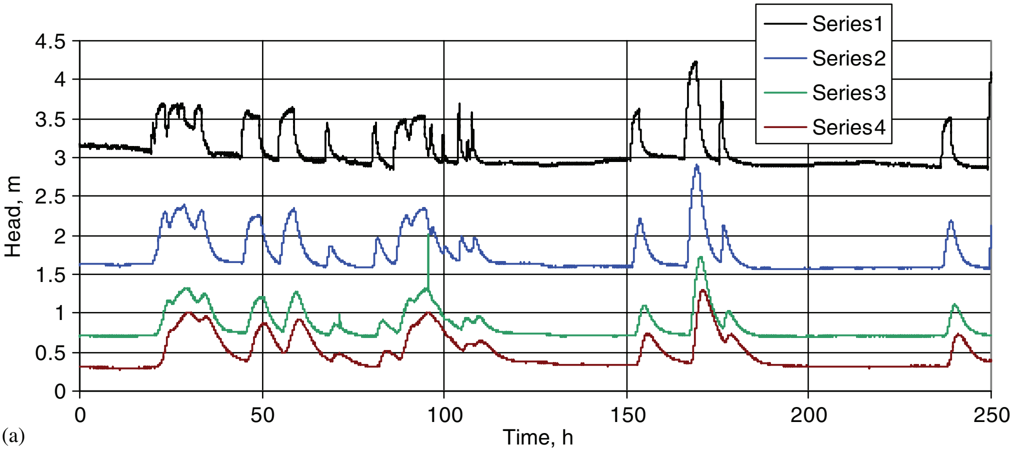
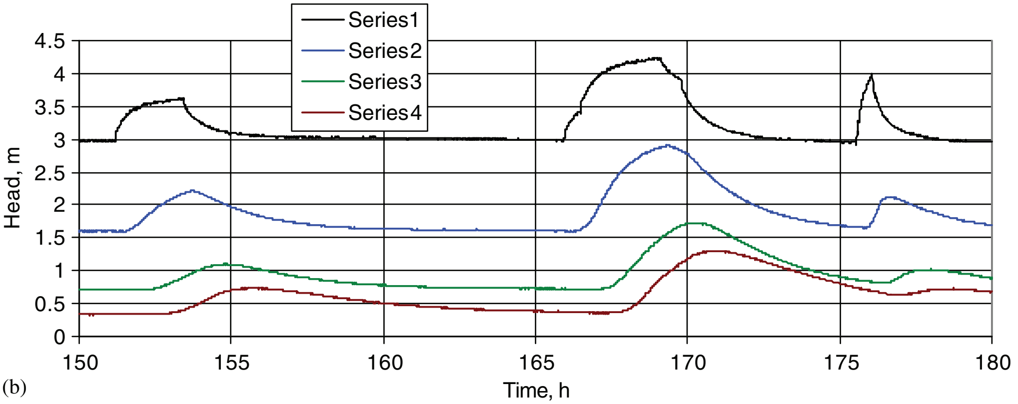


Fig. 3. Hydrographs of the Nemunas for dry (1812), wet (1928) and normal (1885) years.



(a)



(b)

Fig. 4. Nemunas stage graph (a) and its element (b) constructed from data of measurement 2004 09 20 12 to 10 02 12 at distances 0.12 km (series 1), 4.94 km (2), 11.26 km (3) and 14.26 km (4) downstream of HPP.

Maximum and minimum relative flow rates may be read from a statistical hydrograph, and a discharge uniformity coefficient may be computed as

$$k_t = \left(\frac{Q}{Q_o}\right)_{max} \Big/ \left(\frac{Q}{Q_o}\right)_{min} = \frac{Q_{max}}{Q_{min}}.$$

In a case of the Nemunas statistical hydrographs of 1812, 1885 and 1928 we have found averaged $(Q/Q_o)_{max} = 4.144$, $(Q/Q_o)_{min} = 0.4159$ and $k_t = 9.96$.

According to the statistical hydrographs of the Skroblus $(Q/Q_o)_{max} = 1.8077$: $(Q/Q_o)_{min} = 1.8126$; and $k_t = 2.22$. For the Yslykis $k_t = \propto$, $((Q/Q_o)_{min} = 0)$.

3. HPP influence on the river flow regime

The starting and stopping of turbines and the adjustment of their regime to the required power cause sudden water level fluctuations downstream of the HPP (see Fig. 4). Each change of the water level harms the river bed, and the number of turbine starts and stops is not less than the number of days a year. A small power HPP changes its regime of work not less than 2–3 times a day, and maybe more than this. Each adjustment brings about an additional wave of water level fluctuation in the river. Thus, HPP causes up to 1000 peaks of water level fluctuations in the river downstream of the plant, which is dozens of times more than in the natural river without a HPP on it.

According to our in situ investigation data, the speed of the water level drop after the stopping of a turbine depends on the start time and the distance from the HPP (see Fig. 5). Permissible (to save fish fry) maximum drop velocity is 15 cm/h [9]. In this way, the requirements for fish protection are not satisfied in the investigated reach of 14 km length. The distance from the HPP to the end of that section of the reach with unsatisfactory environmental conditions has been obtained through extrapolating the level drop speed–distance relationship (see Fig. 5) to the level of the speed $v = 15\,\text{cm/s}$. The result for a rated case is 19.1 km.

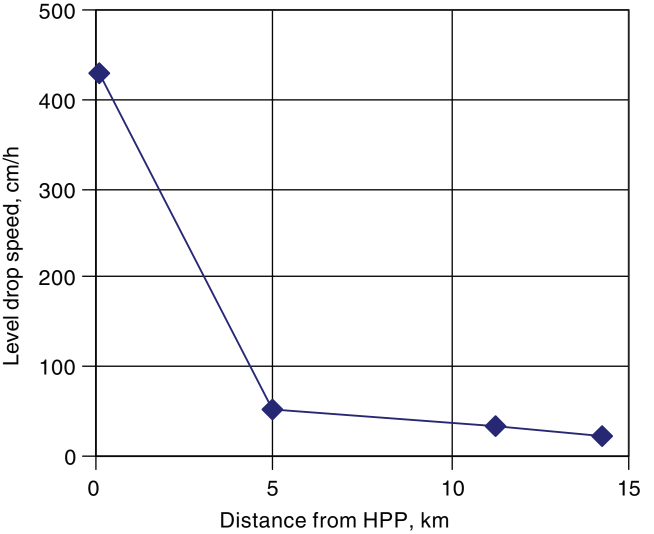


Fig. 5. Level drop speed—distance from Kaunas HPP function graph.

Water level fluctuation speed is closely linked to the tide (reflux) wave propagation along the river speed. According to our investigation, in the reaches between the measured points at the distances of 0.12, 4.94, 11.26 and 14.26 km from Kaunas HPP, the maximum tidal wave propagation speed was 3.21, 2.194 and 1.56 m/s, which is much higher than the mean flow velocity ($\cong$1.0 m/s).

4. The peculiarities of water turbines

The conveyance range of turbines is quite narrow. The ratio of maximum and minimum discharges, called by us as a turbine conveyance coefficient and expressed by $k_t = Q_{t\,max}/Q_{t\,min}$, usually does not exceed 2–3. The coefficient of only cross-flow turbines, especially of those having a runner width limiter [10], may be close to 5.

Most Lithuanian rivers have runoff uniformity coefficient $k_r = Q_{r\,max}/Q_{r\,min}$ higher than that of the turbine conveyance. According to our investigations [11], k_r of the rivers varies within the limits of 10–50. Only a few rivers, such as the Skroblus, with its pure ground water feed (see Fig. 1a) may have rather uniform runoff. A single turbine can pass the whole runoff of such a river without any water accumulation in the HPP reservoir. In most cases two or more turbines are required to pass the river discharge, which may vary within considerable limits.

The turbines of HPP are selected according to the annual discharge of the river. When designing a small HPP the peculiarities of the river flow are seldom taken into account. Usually, several turbines of the same power are selected for a power plant. Flood and drought discharges of the river cannot be passed through such a set of the turbines. Then, the accumulation of water in the reservoir and significant alteration of the river flow are the unavoidable consequences to follow.

The conveyance of water turbines varies within a definite range. It is limited by the admissible drop of machine efficiency. In general, the limits for the working zone of

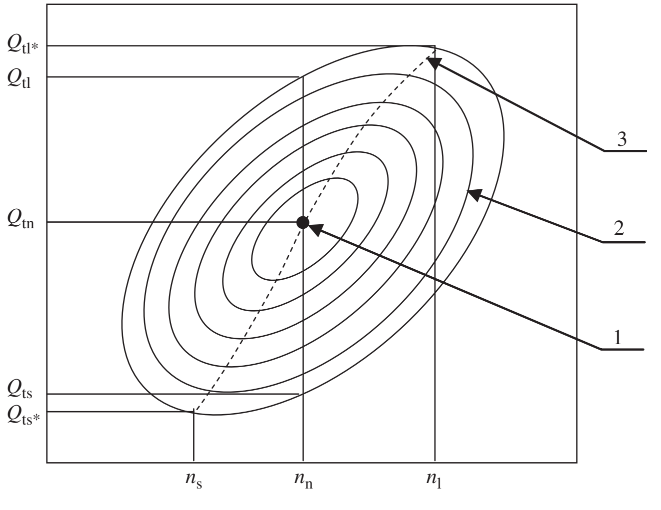


Fig. 6. Turbine hill diagram example: 1-nominal regime point; 2-efficiency isolines; 3-optimal regime line.

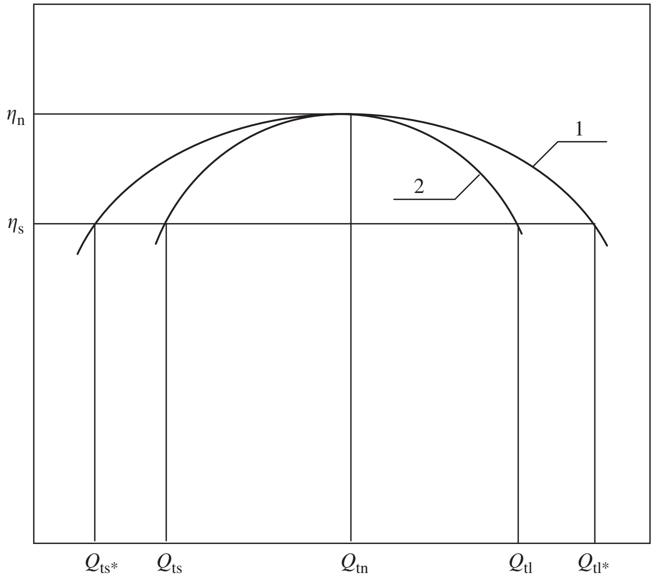


Fig. 7. Graph of $\eta - Q$ relationship for $n = n_v = \text{const}$ (1) ir $n = n_o = \text{var}$ (2).

hydraulic engines may be expressed through the relationship $\eta_m = k_t \eta_v$, where k_t is the regime coefficient and η_v is the nominal efficiency of the machine. Usually, it coincides with the maximum efficiency of the machine. For some hydraulic engines and pumps, the regime coefficient is accepted to be 0.85 [12], which corresponds to an admissible 15% declination from the optimal regime conditions (see Figs. 6 and 7).

The regime coefficient of turbines varies within the limits of 0.85–0.95 and depends on the power of the turbine. For small power Kaplan turbines the coefficient is close to 0.85 [13]. According to hill diagrams (see Fig. 6) of medium power Kaplan turbines of the PL type (OSt 108.023.15–82) their regime zones are determined from $k_t \geqslant 0.94$. Coefficient k_t is close to 1.0. It means that the range of discharge $Q_{min} - Q_{max}$ is not broad. The range may be characterized by the turbine conveyance coefficient $k_{tn} = Q_{min}/Q_{max}$, as we named and denoted it. For investigated by us Kaplan turbines of small power, the coefficient varied within the limits of 2.7–4.2.

River runoff uniformity (in time) coefficient $k_{ru} = Q_{r\,max}/Q_{r\,min}$ usually is much greater if compared to the turbine conveyance coefficient k_{tu}. It means that it is impossible to pass the whole river discharge through a turbine without accumulating water in the reservoir. Very few Lithuanian rivers have uniformity coefficient k_{ru} lower than the highest possible turbine conveyance coefficient, say, for example, $k_{tu\,max} = 4.2$. The Skroblus may be an example of such a rare case of very uniform runoff (in 2000) with $k_{ru} = 2.22 < 4.2$ (see Fig. 1a). Usually, the coefficient of river runoff uniformity exceeds that of turbine conveyance many times over (see Fig. 1).

5. Possibilities for expanding hydropower plant conveyance

The power plant with two or three turbines of the same power has doubled or tripled the conveyance, when compared to a single turbine plant. A great number of turbines of the

same power are required if the river runoff is very irregular. In this case, the installation of several turbines of the same power is irrational. It is much more reasonable to have turbines of different powers.

The smallest power turbine is selected according to the smallest possible discharge of the river. The minimum conveyance of the next turbine should not exceed the maximum discharge of the first turbine. The minimum conveyance of the third turbine should be adjusted to the sum of the maximum discharges of the two smaller turbines; the fourth—to the sum of the maximum discharges of the three smaller turbines, and so on. In such a way, the entire range of river discharges may be covered by two or three, or very occasionally, by four turbines of different powers. If the type and conveyance coefficient of all turbines is accepted of the same magnitude, the number of turbines may be computed by the following equation:

$$(k_{tc} + k_{tc}^2 + k_{tc}^3 + \cdots + k_{tc}^m) \dashv k_{ru},$$

where m is the number of turbines. The term $(k_{tc} + k_{tc}^2 + k_{tc}^3 + \cdots + k_{tc}^m)$ computed for some magnitudes k_{tc} and m are given in Table 1. It is evident from the data that the increment in both the number of turbines and the conveyance coefficient increase the conveyance of the hydropower plant very rapidly. Turbines are expensive. Their price comprises more than 30% of the total price of an HPP [13]. For this reason, the application of turbines with a broad range of conveyance seems to be more promising than increasing the number of turbines.

The investigation of turbines with a broad range of conveyance has brought us to the choice of a cross flow turbine [10]. The conveyance coefficient of this turbine reaches 5. In addition the coefficient may be increased by a simple modification—by introducing a divisor to a turbine runner (see Fig. 8). The turbine with a divider can work at one-third and two-thirds width, and a full runner width serves as two or even three turbines of different conveyance. Here it should be mentioned that the efficiency of the turbine, working with one-third or two-thirds of the runner width is lower than that of a turbine working with full its width.

The turbines of standard HPPs work at a constant rotational speed. In this case, the turbine operation zone may be characterized by the vertical line 1–2 (see Fig. 6). Declination from the nominal regime point N causes a quite sudden drop in turbine efficiency.

The maximum efficiency point for any discharge can be found on a hill diagram. The points of maximum efficiency form lines of the optimal regime. The line embraces a broader range of discharges Q_{ts*}–Q_{tl*}. Besides any point of the line corresponding to

Table 1
The term $(k_{tc} + k_{tc}^2 + k_{tc}^3 + \cdots + k_{tc}^m)$ for some magnitudes of k_{tc} and m

Coefficient k_{tc}	Number of turbines m				
	1	2	3	4	5
1	1	2	3	4	5
2	2	6	14	30	62
3	3	12	39	110	353
4	4	20	84	340	1364

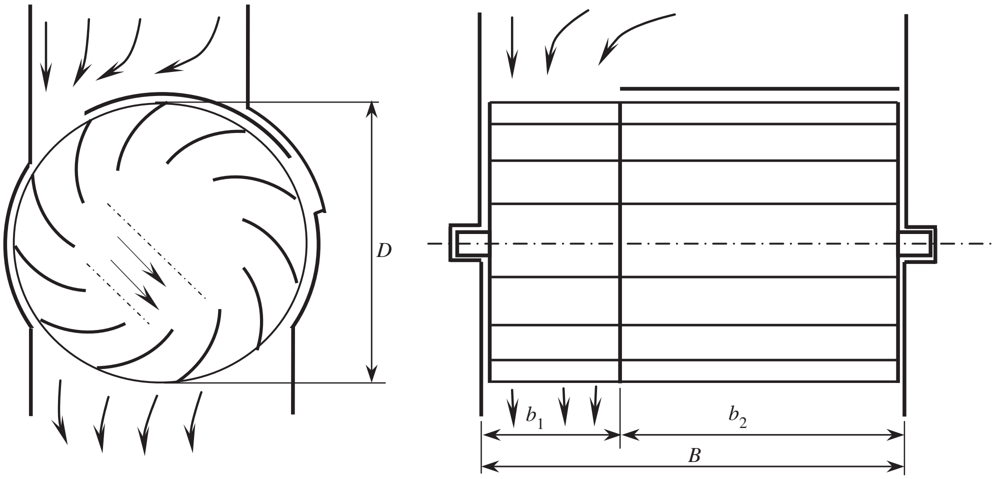


Fig. 8. Diagram of a cross flow turbine, its dimensions and water motion directions.

a definite discharge, the efficiency is the maximum possible for this discharge (see Fig. 6). Thus, the variable rotational speed regime carries the potential for expanding the turbine conveyance to increase its efficiency.

6. Mechatronic systems of a hydropower plant

The rotational speed of traditional HPP turbines is related to the frequency of electro power. A special mechatronic system is necessary to control the mechanical and electrical equipment of a hydropower plant, to convert the electric current of free parameters into the alternating current of standard parameters, and to realize the idea of varying speed turbine regimes.

A structural diagram of a mechatronic system for the control of the plant with turbines working under a varying speed regime is given in Fig. 9. The turbine rotates a pulsating field generator (G) without an intermediate speed-reducer. The alternating current frequency varies according to the speed of turbine rotation. The cycle-converter (CC) transforms the current of varying frequency into the stable frequency (50 Hz) three-phase current. The control system (CS) forms the fixed and stable frequency and the phase shift of a three-phase current. The pulses formed by CC currents are not sinusoidal; therefore, an electric filters system is used to improve their harmonic composition. The obtained energy of standard parameters can be supplied to the consumer, which is denoted by A. The current can also be supplied to the excitation unit (EU) and to the accumulator (A), which, in the case of a small HPP, serves simultaneously as a voltage stabilizer (VS). Either a regenerative electric-chemical accumulator REDOX or an electrochemical generator of hydrogen can be used for a larger power plant producing energy for storage. In the case where an electric network (EN) is nearby, it may by used to realize the produced energy, and also as a reserve source of energy; then the hydropower plant may work both in autonomous and system modes, optimally utilizing river flow energy.

The electric circuit of a pulsating field generator–cycle-converter system is shown in Fig. 10. Here, *G* is one-phase pulsating field generator; CT are adjusted cycles

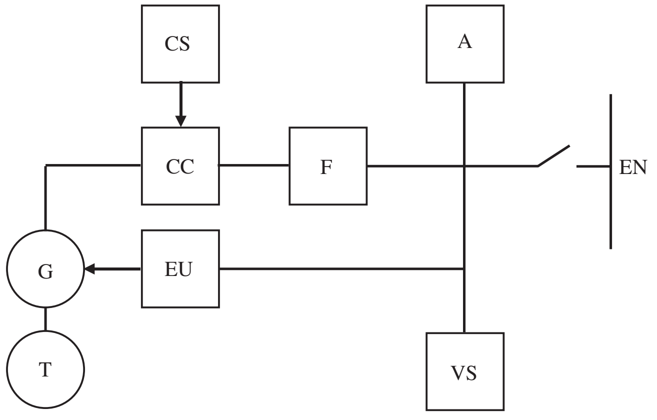


Fig. 9. Structural diagram of a mechatronic system for a micro-hydropower plant.

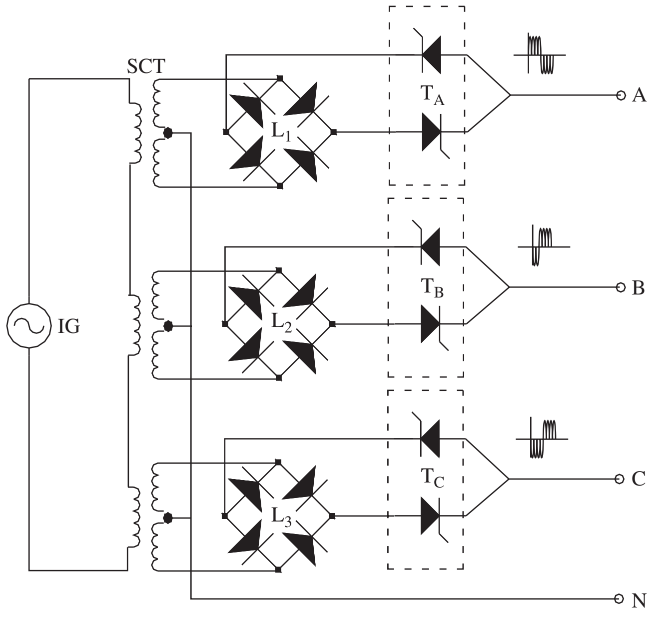


Fig. 10. Principal design of an inductive generator–cycle-converter system.

transformers; L_1, L_2, L_3 are cycle rectifiers; T_A, T_B, T_C are cycle thyristors. The modules of cycle rectifiers and thyristors form three-phase currents of standard parameters from one-phase higher frequency semi-cycles.

The shape of these currents is nearly rectangular. On the basis of known conceptions [14] we have developed a modified cycle-converter, which allows the transformation of rectangular pulses into sinusoid ones. The application of the modified cycle-converter makes it possible to considerably simplify the system of current shape improvement filters and to upgrade the technical–economical parameters of the whole of the system.

7. Mathematical simulation models of the processes

To simulate a small HPP mechatronic system the following respective nominal parameters are necessary: turbine rotational speed n_v, water discharge Q_v, pressure head H_v, efficiency P_v, and the likelihood occurring of maximum and minimum rotational speeds of a turbine $n_{\max}$ and $n_{\min}$. In addition, it is necessary to be aware of the following parameter relationships $n-Q$, η_t-Q and P_t-Q [15].

For a numerical example let us take the following initial data: $n_v = 750\,\text{rev/min}$, $Q_v = 2.3\,\text{m}^3/\text{s}$, $H = 5.50\,\text{m}$, $P_v = 110\,\text{kW}$, $n_d/n_v = 1.8$. The relationships $n-Q$, η_t-Q and P_t-Q are known for the Kaplan turbine, whose model has been tested under laboratory conditions [11]. The range of the turbine conveyance is $Q = (1.63-3.00)\,\text{m}^3/\text{s}$. The parameters data is represented in Table 2.

According to the experimental data the following relationships (correlative and approximate) are constructed:

for $\eta-Q$ relationship:

$$n = 319.9Q + 0.414, \tag{1}$$

with regression coefficient $r = 0.99$:

for $\eta-n$ approximate relationship:

$$\eta_t = 0.86\,\sin[(1.978n + 86.1)10^{-3}]|_{n=500}^{n=1000}. \tag{2}$$

According to MULTISIM-2001 program [16], function sin $(1.978n+86.1)10^{-3}$ has been expanded by the Makloren Series. Neglecting its fourth and next members, in order to construct a mathematical model we have created the following formula:

$$\eta_t = \left\{(1.7n + 74.1)10^{-3}\left[\frac{1}{1!} - \frac{1.978n + 86.1}{3!} + \frac{(1.978n + 86.1)10^2}{5!}\right]\right\}|_{n=500}^{n=1000} \tag{3}$$

Taking into account the expressions n, η_t (1), (3) and accepting $H = 5.5\,\text{m} = \text{const}$ we obtain the following dependence of turbine power on discharge and efficiency:

$$P_t = 9.81HQ\eta_t = 53.96Q\eta_t. \tag{4}$$

Here, head H is expressed in m, Q in m^3/s and P_t in kW.

In terms of Eqs. (1)–(4), introducing some simplifications we set up a mathematical model of a stationary process in a turbine. Dimensional and dimensionless parameters are expressed by the voltage of direct current of a corresponding voltage. Mathematical

Table 2
Parameters of the turbine under consideration

No	Discharge Q, m^3/s	Rotational speed n, rev/min	Efficiency, η_t,—	Power P, kW	Notes
1	1.63	517	0.77	67.7	Minimum discharge
2	2.3	729	0.87	108.0	Nominal discharge
3	3.0	967	0.77	124.7	Maximum discharge

operations have been performed by means of the above-mentioned computer program MULTISIM-2001.

In computations the numerical variables are expressed by voltages, and their control is performed by voltmeters (see Fig. 11). The simulation is performed by introducing discharge Q as an independent variable into a mathematical model structure. The computation results—dependent variables n, η_t and P_t are read from the indicators. The simulation results are used for the mathematical model of a turbine–generator unit. On the basis of simulation results Eqs. (1)–(3) have been derived. Their graphical view is given in Fig. 12.

The comparison of experimental and mathematical simulation results of a turbine has yielded the following relative declination for discharge $\delta = \pm 3.8\%$, for efficiency

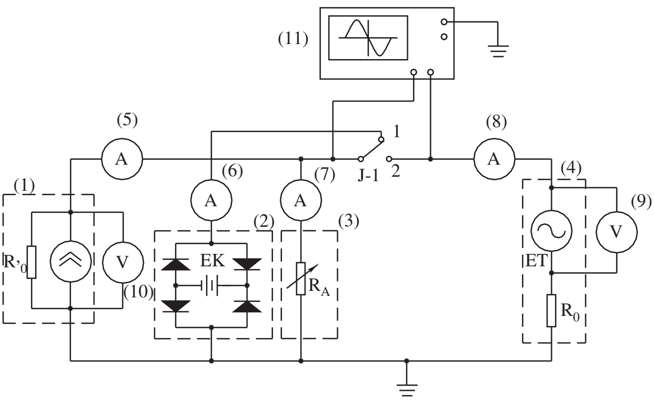


Fig. 11. Simulation model of a cycle-converter and its functional load.

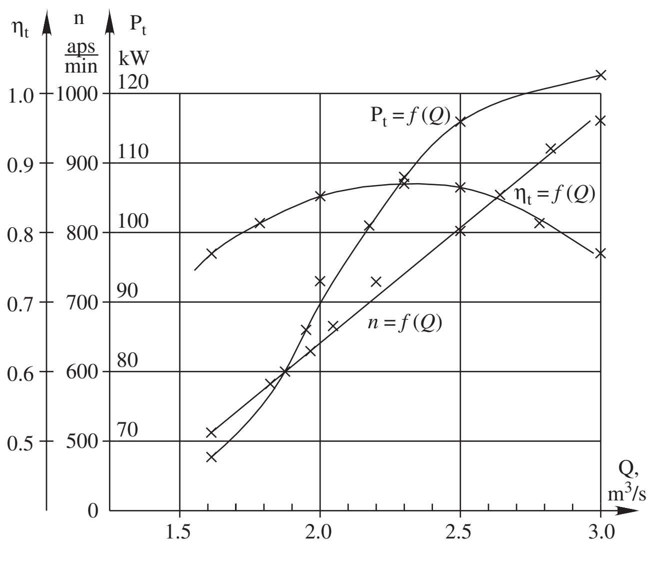


Fig. 12. Graphical view of turbine mathematical simulation results.

Table 3
Characteristics of turbine, generator and cycle-converter

Discharge Q, m^3/s	Rotational speed n, rev/min	Work in autonomous mode duty			Work in system mode duty		
		Voltage U, V	Current I_1, A	Current I_2, A	Voltage U, V	Current I_1, A	Current I_2, A
1.63	511	218	71.2	21.8	224	22.4	68.4
2.30	729	221	116.0	22.1	226	22.6	113.0
3.00	967	222	161.0	22.2	228	22.8	158.0

$\delta_\eta = \pm 3.13\%$, and for power $\delta_{Pt} = \pm 4.0\%$. They all are acceptable for practical application.

A similar mathematical model has been set up, and investigations have been carried out on IG of 100 kW power, and the possibilities of applying the obtained results have been identified. The application of the possibilities depends on the nature of the working area [15]. In addition, the model for investigating CC modification possibilities has been prepared and investigated. For investigation of the harmonic composition of industrial parameters formed by the CC current MULTISIM-2001 program, based on the Furje series, has been used. The investigation of CC simulation models has enabled us to determine the influence of system modes to the parameters of electric energy quality (voltage and frequency declination from standard).

Real CC and its functional load in a simulation model is substituted by the quasi-stable current source of an ideal sinus shape. Accumulator 2 (see Fig. 11) is simulated by a rectifier with an accumulator, an autonomous load 3—by resistor R_a, energetic system, and electric network EN—by the alternating current source of industrial frequency (50 Hz). Indicators 5, 6, 7, 8, 9 and 10 are designed to measure the current and voltage of the modes, and oscilloscope—to investigate the voltage—time function. The autonomous mode with the operational energy store, or the system mode, with or without the store, are started by switch J-1.

The simulation model described above was used to investigate typical working regimes. It should be noted that such an important parameter as frequency is completely independent of both turbine rotation frequency and the magnitude of power plant load. Using the model we have investigated autonomous and system regimes within the ranges of discharge $Q = (1.63-3.00)\,m^3/s$ and revolution frequency $n = (511–967)$ rev/min.

The investigation results are presented in Table 3. According to them the voltage changes within the limits of U (218–222) V, loading current—I_1 (71.2–161) A, and accumulator current—I_2 (21.8–22.2) A. For a power plant working on a system mode the voltage varies within the limits of (224–228) V, loading current—I_1 (22.4–22.8) A, and accumulation current—I_2 (68.4–158) A (see Table 3).

8. Conclusions

1. Typical hydropower plants with one or more turbines of the same power affect and harm the environment.
2. Two or more turbines of different power should be used in hydropower plants to reduce its influence on river flow and the environment.

3. Cross flow turbines have a wide range of conveyance, therefore they may be recommended for broader application in the development of small river hydropower.
4. The application of mechatronic systems and the proper adjustment and conversion of energy flows in the links of electric systems create the possibility of exploiting turbines in the varying rotational speed mode and harmonising the work of plants with the environment.

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